FINAL REPORT

ANIMATION APPRENTICE WELDING ROBOT FOR SHIPYARD APPLICATION

DECEMBER 1983

BY:

TODD PACIFIC SHIPYARDS CORPORATION

Los Angeles Division

710 Front Street

San Pedro, CA 90733

UNDER:

MARAD CONTRACT NO. MA-80-SAC-0104 1

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1. Scope

The overall objective of this study was to evaluate the applicability of the portable Unimation Apprentice Welding Robot for the shipbuilding industry. This evaluation was then to serve-as a guide for introducing this technology into shipbuilding with an expected increase in productivity. The anticipated result was to have a base of information upon which shipbuilders might use to further the application of flexible welding automation in shipbuilding. Unfortunately, because of events discussed in this report, the planned progress to meet the objectives had setbacks. The SP-7 Panel therefore thought it best to cancel this study before the objectives could be reached.

1.1 Prime Objectives

The following were the primary objectives this study was charged with determining:

1.1.1 Portability

Identify which carriage system would give the Apprentice Robot true portability. Determine if the degree of portability this robot offered was adequate.

1.1.2 Applicability

Identify and develop areas of application, workplaces and welding processes which this robot could operate successfully.

1.1.3 Cost Effective

Determine if the robot was cost effective at the different applications tested.

1.2 Secondary Objectives

The following were secondary objectives that would be learned from the primary objectives.

1.2.1 Improvements

Develop a list of recommendations and improvements to further meet the primary objectives.

1.2.2 Implementation

Document requirements for implementation of this robot into a production environment.

2. Technical Approach

The general approach taken to evaluate the Apprentice Robot was to set-up, debug, perform qualification tests and operate the robot at various application sites. These sites were to use production workplaces when practical to gather meaningful data. To be noted were the necessary transport, tooling, facilities and support equipment required for each site application.

2.1 Orientation and Planning

Todd personnel were sent to Unimation’s Danbury, Conn. facilities for training. Personnel sent were: two welding operators, one plant electrician, one welding technician, one welding engineer. Personnel were trained in the Apprentice’s operational capabilities, welding and programming techniques, maintenance and trouble-shooting. Also, personnel were given a tour of Unimation's manufacturing facilities where Apprentice Robots were being used in production.

Planning to control data recovery and cost control were made as follows: A daily Jog of all problems, events and parameters used was kept by the project engineer. Cost was controlled by having all charges made against this contract approved by the project engineer, and all invoices and time charges reviewed by the Finance Department. A monthly computer printout was made of all charges.

2.2 Equipment

The equipment obtained was that recommended by Unimation which was readily adaptable with the Apprentice Robot. See Exhibit 1 for Equipment Literature.

2.2.1 Power Source & Wire Feeder

Linde 650, ratedat 650 amps at 44VDC, 100% duty cycle. Output is SCRcontrolled with. CVand CC modes.

Linde Digimig Robot 5, has 5 preset weld schedules (ipm+ volts), abort output signal and external terminal strip for hard wiring to the Apprentice Robot.

2.2.2 Apprentice Robot

Unimation Apprentice Robot, an electrically driven, numerically controlled, programmable five-axis welding robot. Table 1 lists the robot specifications.

2.2.3 Welding Torches

Linde MT 500; this is an air cooled robot wetding torch rated at 500 amps with $C0_2$.

TABLE 1

ITEM	PARAMETER
Clearance Dimensions:	
Electronic Console Assembly	30 x 16 x 21 inches
Mechanical Assembly	21 x 22 x 68 inches
Weight	
Electronic Console Assembly	200 pounds
Mechanical Assembly	125 pounds
Torch Holder	1-3/8 inch maximum diameter (straight nozzle)
Maximum Load (Weight of Torch)	10 pounds
Maximum Operating Parameters of Arm (Full Extension)	
Zed	35-inch stroke, 45-inch reach
Roll	64 inches (90 degrees)
Yaw	Plus or minus 180 degrees
Pitch	64 inches (90 degrees)
Wrist Bend (Fifth Axis)	165 degrees 1 or 2 positions
Welding Specifications:	
Velocity	0.4 to 48 inches per minute
Number of Weld Speeds/Program	Four
Number of Weld Currents	Up to four
Transfer Speed	2 inches per second
Weave Channels	Two
Dwell	0.1 to 2.9 seconds
Weave Frequency	0.1 to 1 second
Weave Amplitude	0.12 to 1.20 inches, peak to peak
Number of Welds	14 per program
Weld Path	27 feet
Power Requirements	1KCA, 115V $^{+10}_{-15}$ %, single phase 60 Hz, 230/460V, three phase 60 Hz (others available)

TABLE 1 (continued)

ITEM	PARAMETER
Environmental Conditions:	
Ambient Temperature Humidity	32°F to'120°F (O to 50°C) O to 90% noncondensing
Routine Check	8 hours (backlash) of motion
Programming	Record-playback
Memory	Solid state, 8K capacity (Battery Held)

2.2.3 Welding Torches (cont'd)

Tweco No. 4; this is an air cooled semi-automatic welding torch that Todd adapted to this robot. It is rated at 400 amps with $C0_2$.

2.2.4 Support Equipment

Linde wire straightener
Linde CO_2 flow meters
Arc-Tight electrical connectors
Todd fabricated manual 2-axis positioning table
Nylon vinyl covers for robot and support equipment

2.3 Areas of Evaluation

2.3.1 Plate Shop - Plate Shop fabricates small to medium size subassemblies and components, this includes rudder, stern tubes, foundations, bulkheads, etc. This shop is covered and has two overhead bridge cranes. The Plate Shop was chosen as the first test site for several reasons. First, the quantity and type of production workplaces assembled here were more applicable to the envelope limitations and programming capabilities of the Apprentice. Second, this shop provided a secure indoor environment with the proper utilities to service the robot. This was desirable for initial start up and testing.

2.3.2 Other Areas

No other areas were evaluated due to cancellation of this study.

2.4 Working Carriages

The key to portability for the Apprentice Robot is in the design of the carriage. Several carriages were to be tested; cart mount on wheels, cart mount for lifting equipment and gantry mount. The cart mount on wheels was chosen as the first carriage to test.

2.4.1 Cart Mount on Wheels

This carriage design was chosen first because it offered some advantages for use in the Plate Shop which the other carriage designs lacked. This carriage allowed the robot to be utilized as a complete package which needed only a primary power source input. It could be wheeled around the Plate Shop with relative ease by one person and allowed access to work fixtured around the borders of the fixturing platens. The carriage was fabricated by Todd and was of Unimation's design which provides lateral movement of the robot gimbal for a distance of 35 inches. See Figure 1 for drawing of this carriage.

2.4.2 Other Carriages

No other carriage mounts were tested due to the cancellation of this study.

2.5 Applications

2.5.1 Plate Shop

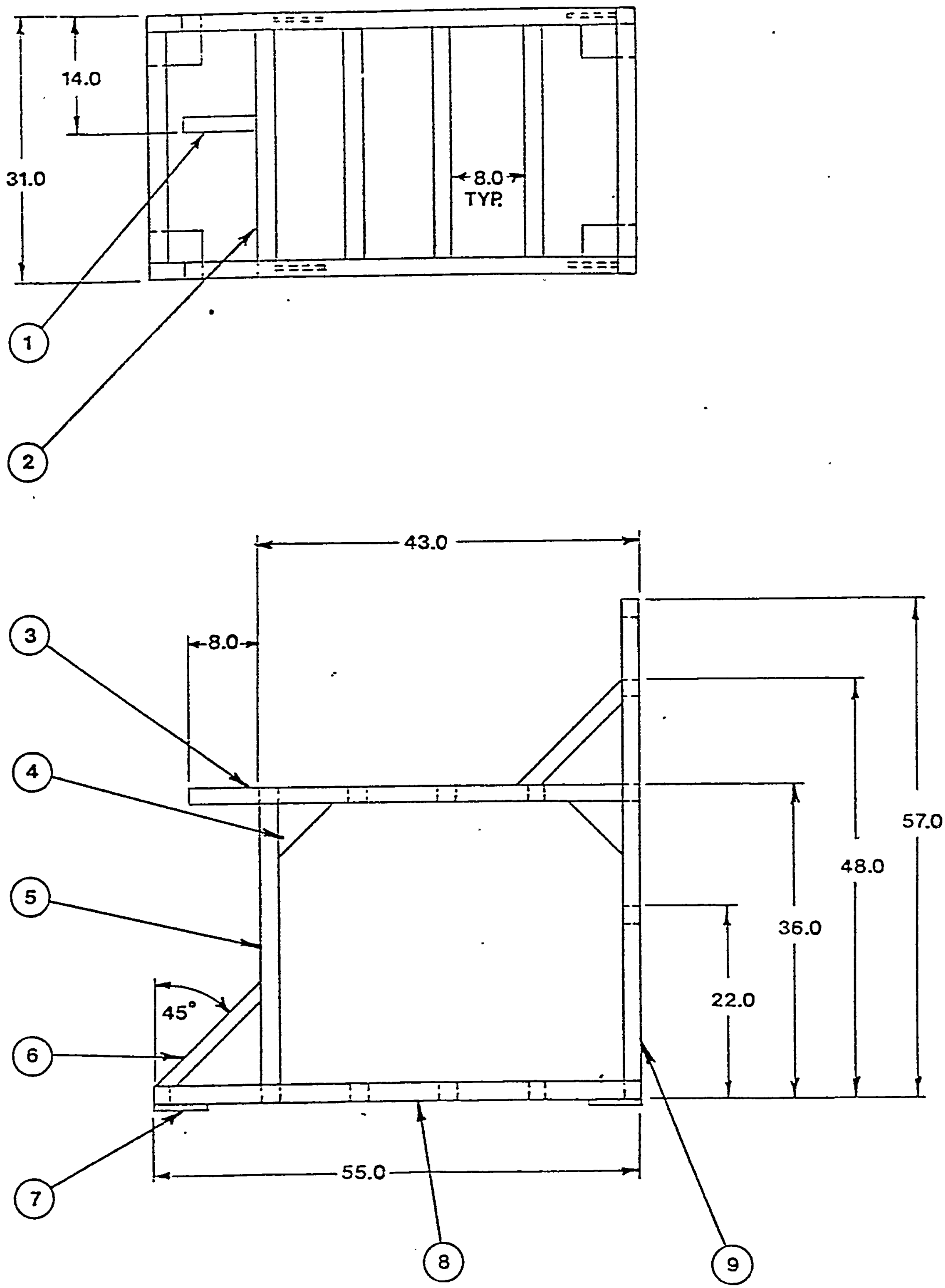
The applications which were chosen for testing in the Plate Shop were not used due to the cancellation of this project. However, the test coupons used during initial start-up, debugging and performance qualification are shown in Figure 2. These test coupons included fillet weld tee test assemblies, C-channel-to-stiffener joint assemblies and pipe-to-collar assemblies.

3. Performance

The cancellation of this study before any production work was tested precluded most of the performance evaluations. Conclusions as to adaptability at various shipyard locations, portability with several carriages, cost effectiveness and implementation were not possible. Performance during the start-up and qualification phases is given as follows.

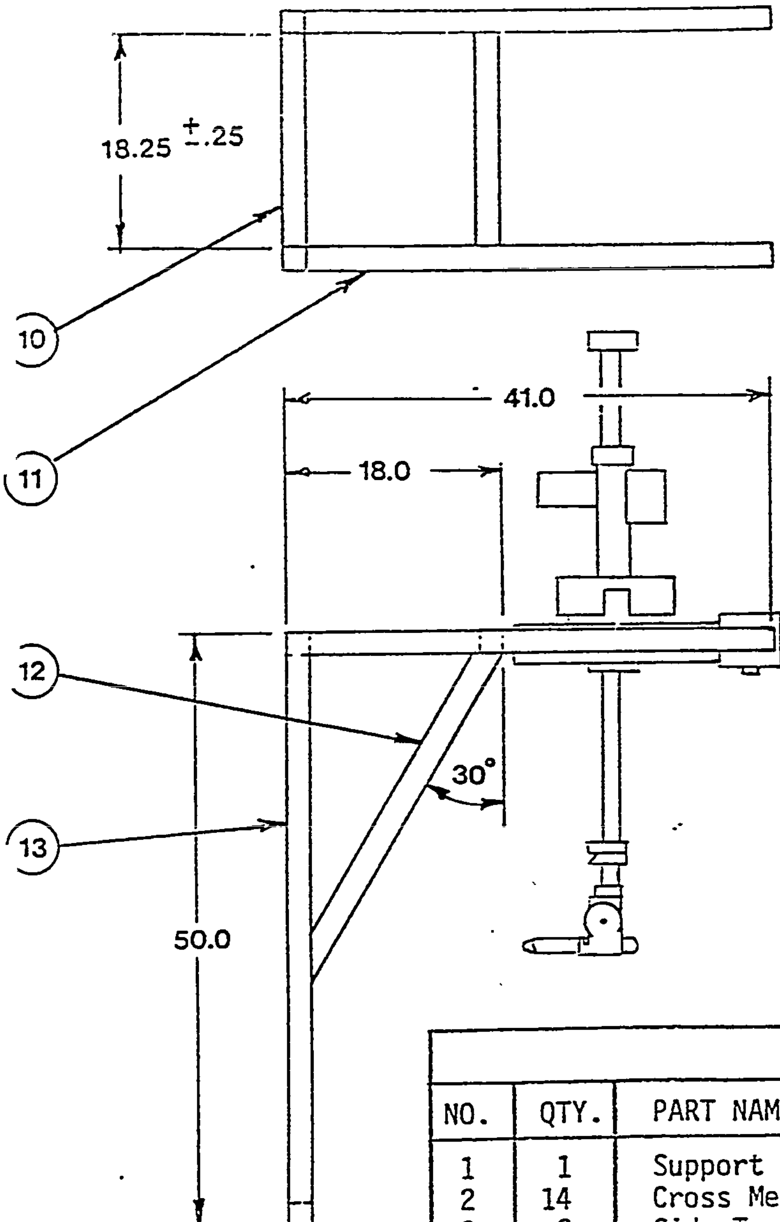
3.1 Power Source & Wirefeeder

Both the Linde 650 power source and Linde Digimig Robot 5 performed well. The Linde 650 was delivered with a bad PC board which was replaced. The Linde Digimig Robot 5 was easily hard wired into the Apprentice with no malfunctions during the entire study.



CART MOUNT ON WHEELS CARRIAGE

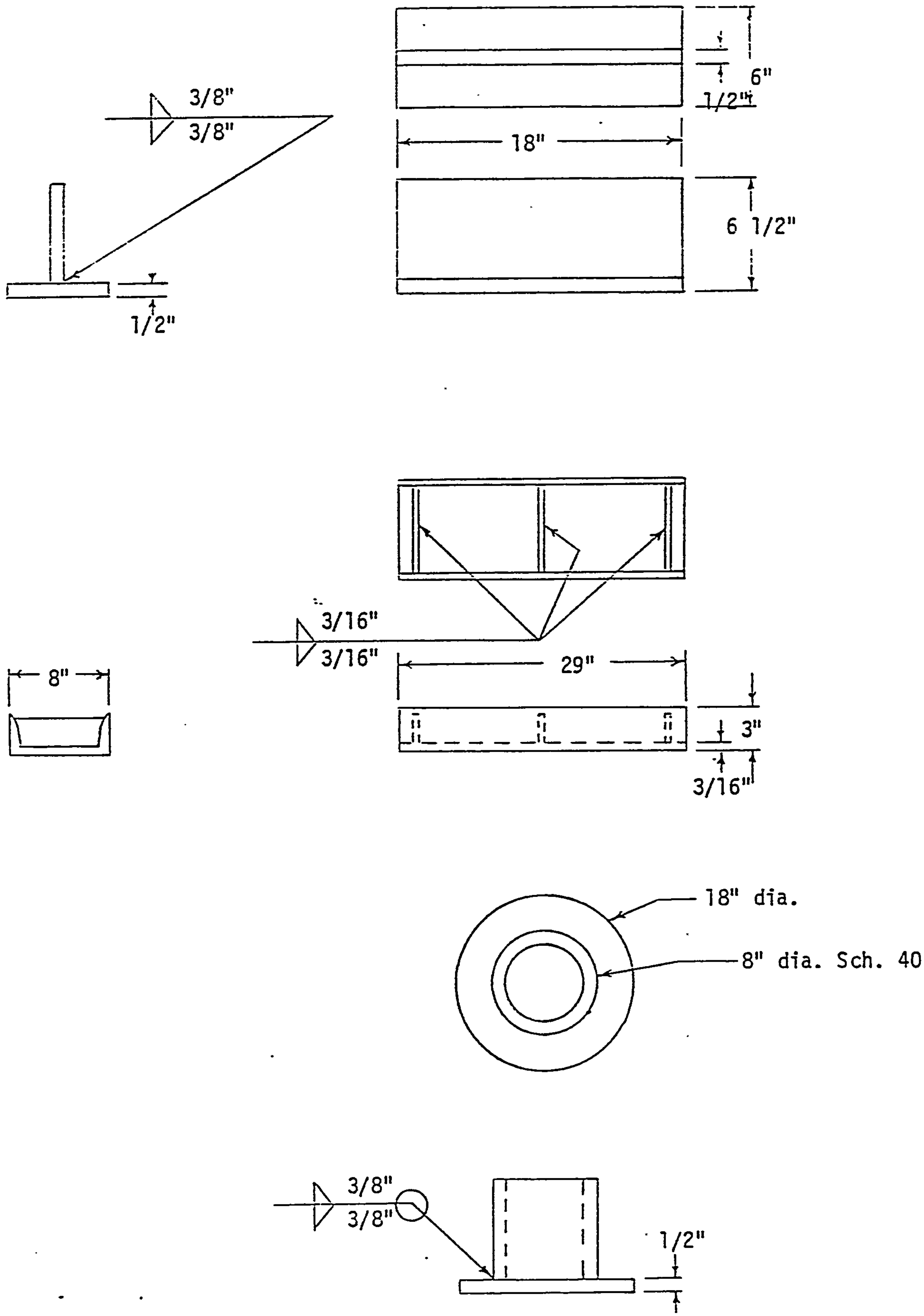
FIGURE 1



MATERIALS LIST				
NO.	QTY.	PART NAME	MATERIAL	REMARKS
1	1	Support	Tubing 2" sq. 1/8 wall	8" lon
2	14	Cross Member	Tubing 2" sq. 1/8 wall	27" lon
3	2	Side Top	Tubing 2" sq. 1/8 wall	49" lon
4	4	Gusset	HRS 1/2 x 6 x 6	
5	2	Vertical Rear	Tubing 2" sq. 1/8 wall	32" lon
6	4	Gusset	Tubing 2" sq. 1/8 wall	17" lon
7	4	Mounting Plate	HRS 1/2 x 6 x 6	
8	2	Side Bottom	Tubing 2" sq. 1/8 wall	53" lon
9	2	Vertical Front	Tubing 2" sq. 1/8 wall	57" lon
10	3	Cross Member	Tubing 2" sq. 1/8 wall	18" lon
11	2	Horizontal	Tubing 2" sq. 1/8 wall	39" lon
12	2	Gusset	Tubing 2" sq. 1/8 wall	32" lon
13	2	Vertical	Tubing 2" sq. 1/8 wall	50" lon

CART MOUNT ON WHEELS CARRIAGE

FIGURE 1 (cont'd)



TEST COUPONS
FIGURE 2

3.2 Apprentice Robot

The performance of the Apprentice will be discussed by component. Components to the Apprentice are described as: -

- Gimbal and Pole Assembl
- Controller
- Teach Wheel
- Wrist Assembly

The Apprentice was delivered 12/28/82 and assembled with the associated welding equipment in a complete system by 2/15/83. From this date until the cancellation of the study, the robot was being debugged, modified and tested for performance qualification. There were numerous problems which occurred that delayed the progress of the study and for which Unimation field service personnel were called in. Some of the problems which arose are listed in the order of their frequency of occurence. These problems will be discussed in the sections following.

- Excessive movement in nesting assembly
- Excessive movement in wrist assembly
- Memory loss in hot environment
- Low reliability/durability

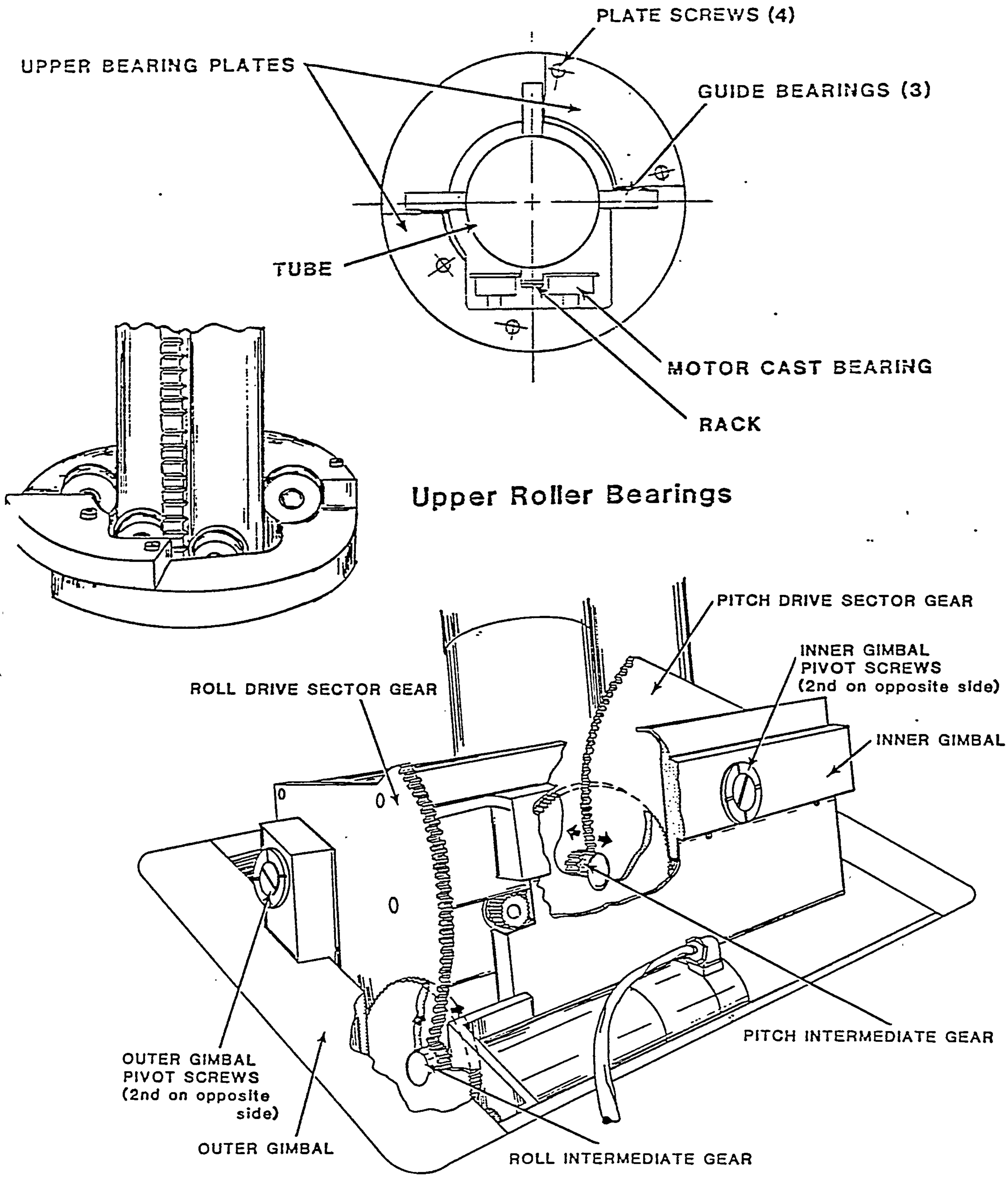
The Apprentice Robot as a whole was simple and fast to program/teach which provided flexibility for quickly working various test pieces. However, frequent repairs and maintenance plagued the robot from the beginning of this study, consequently, performance data relating to the objectives of the study are few. Reliability and maintenance performance was not acceptable for shipyard application.

3.2.1 Gimbal and Pole Assembly

This assembly consists of a gimbaled frame with electrically driven gears for gimbal movement. At the center of this gimbaled frame is the armor center pole which is driven through a rack and pinion with guide rolls around the pole to provide accurate lateral movement. See Figure 3 for illustration. The performance of this assembly was not very satisfactory even though good quality welds were made. The reasons being; poor reliability, frequent maintenance and limited capabilities. The durability of this assembly in a shipyard environment is not satisfactory.

3.2.1.1 Drive Gears

Unimation replaced all the gimbal drive gears as an update. The new gear set incorporated an increased gear angle which improved the movement noticeably in the teach mode. Backlash in the gears and rollers required frequent adjustment to maintain accuracy at the welding torch. The drive gears, pinion, rollers



GIMBAL AND POLE ASSEMBLY

FIGURE 3

3.2.1.1 Drive Gears (cont'd)

and pole were all of open construction which did not prevent dust and grit from collecting on them. This meant that daily cleaning of these components was necessary.

3.2.1.2 CenterPole/Arm

The center pole was of light construction. Small dents and/or nicks on the pole in the path of the rollers rendered the pole inoperative. This occurred after two months of use and the center pole was replaced by Unimation.

3.2.1.3 Accuracy

The accuracy in gimbal/pole and wrist assemblies combined was ± 1/32" for the 0 to 2/3 pole extension positions and ± 1/16" for pole extensions of greater than 2/3. These tolerances were measured at the end of the torch.

3.2.1.4 Nesting Assembly

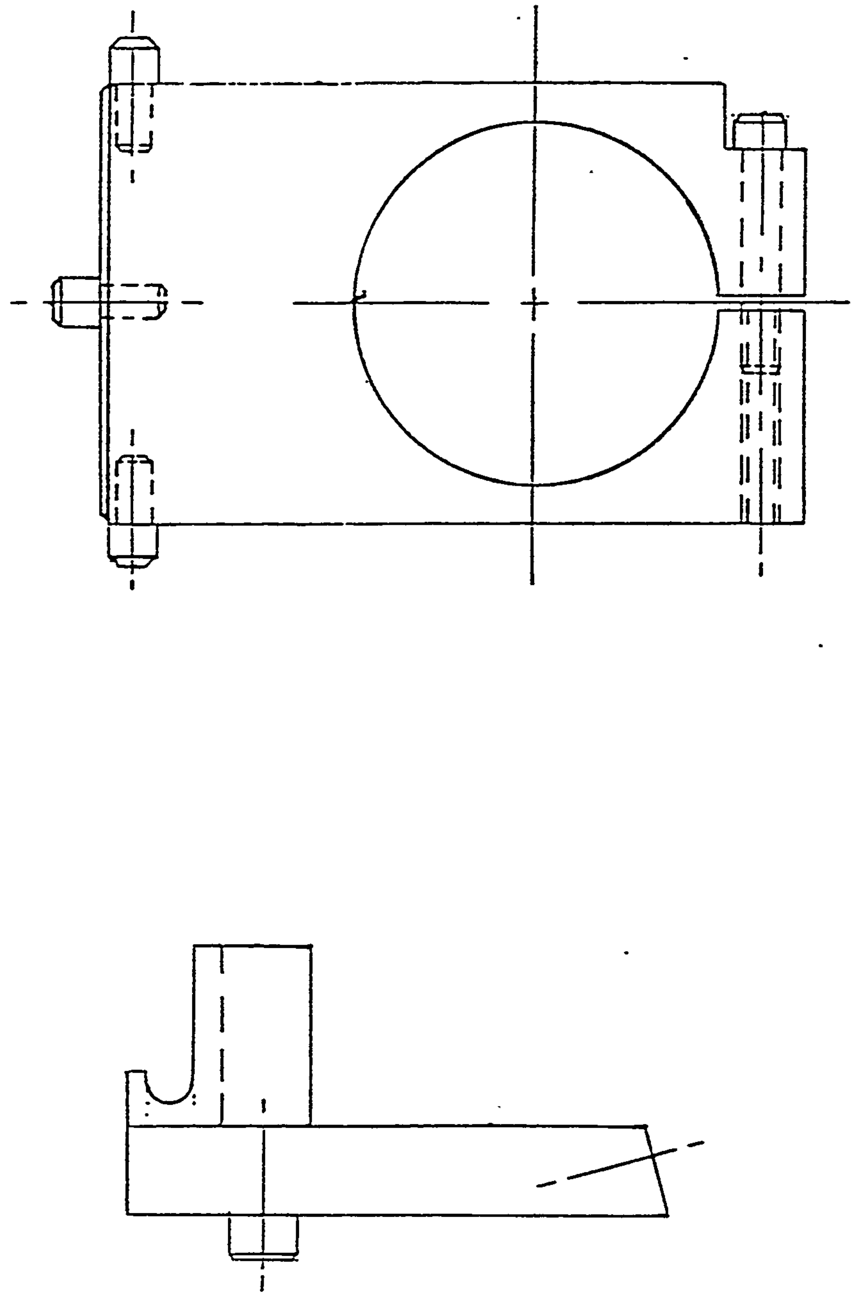
The pole/arm required accurate positioning at a home location (nest) from the start of all programs. This provided the robot controller with a reference point from which all other movements were determined. This positioning was accomplished by a pin-in-groove assembly (nest). The pins were located on the tube while the grooved nesting block was located at any convenient location within the robot envelope. Inaccuracies were caused in this assembly because of slippage and poor seating between the pin and the grooved nesting block, see Figure 4. Minor movements in the nest were magnified as the torch moved further from the nest. Unimation has redesigned this nesting assembly, however; it was not tested.

3.2.1.5 Lubrication

The recommended lubricant for the drive gears and other moving parts was a molybdenum base spray. This spray was used initially but after continued use clogged the gears and resulted in stiff erratic movement, particularly in the teach mode. A petroleum base spray was substituted which eliminated the stiffness but attracted dust and required daily cleaning and re-application.

3.2.1.6 Transfer Speed

The speed of the torch when moving from the nest to the weld, between welds and from the weld to the nest



NESTING ASSEMBLY

FIGURE 4

3.2.1.6 Transfer Speed (cont'd)

is referred to as transfer speed. The transfer speed is set at two inches per second. This speed is excessively slow and increases the program time, particularly on test pieces with numerous program steps (welds).

3.2.1.7 "Weight and Envelope

The weight of the gimbal and pole assembly did not permit its movement without a carriage that cou1d be either rolled or mechanically lifted. The envelope, the gimbal and pole prescribed was the shape of a truncated symmetrical cone with the top and bottom diameters of approximately 64" and 12", respectively. This envelope limited the size of workplaces to relatively small pieces. See Figure 5.

3.2.2 Controller

The robot controller contains all the necessary electronics to control the movements of the robot manipulator and interface with the welding equipment. See Figure 6.

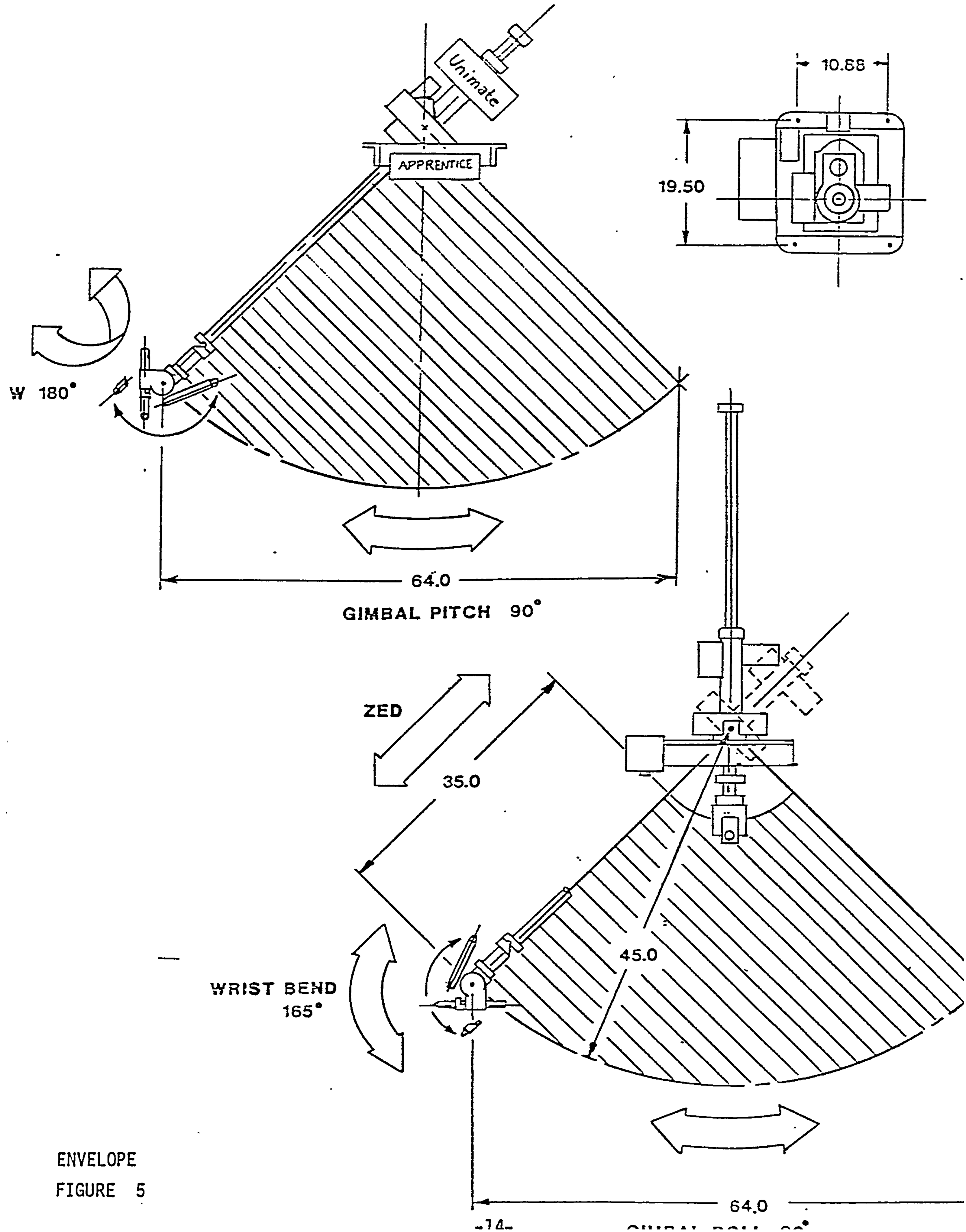
3.2.2.1 Programming

The controller allows for a maximum of 15 program steps to be used, one of which must be taken to end the program. There are 4 weld schedules and 2 weave sequences which can be selected. The 15 program steps were adequate for most of the test pieces. However, . one test piece involved welding three stiffeners into a C-channel, see Figure 2. This normally would have required six program steps to weld both sides of one stiffener. There were obviously not enough program steps to accomplish this task. This was seen as a severe limitation in welding planned for production workpieces.

3.2.2.2 Travel Speed and Weave

The four weld schedules each have separate travel speed adjustment pots. These pots can be used while the welding operation is on. The pots are very sensitive and difficult to properly adjust. Also, repeatability was nonexistent when moving the pot to a position which had previously been used and for which a travel speed had been noted.

The controller provided selection of two weave sequences with adjustments for end dwell, center dwell, weave speed and weave amplitude, See Figure 7. The weave



ENVELOPE
FIGURE 5

APPRENTICE COMPONENT INTERCONNECT

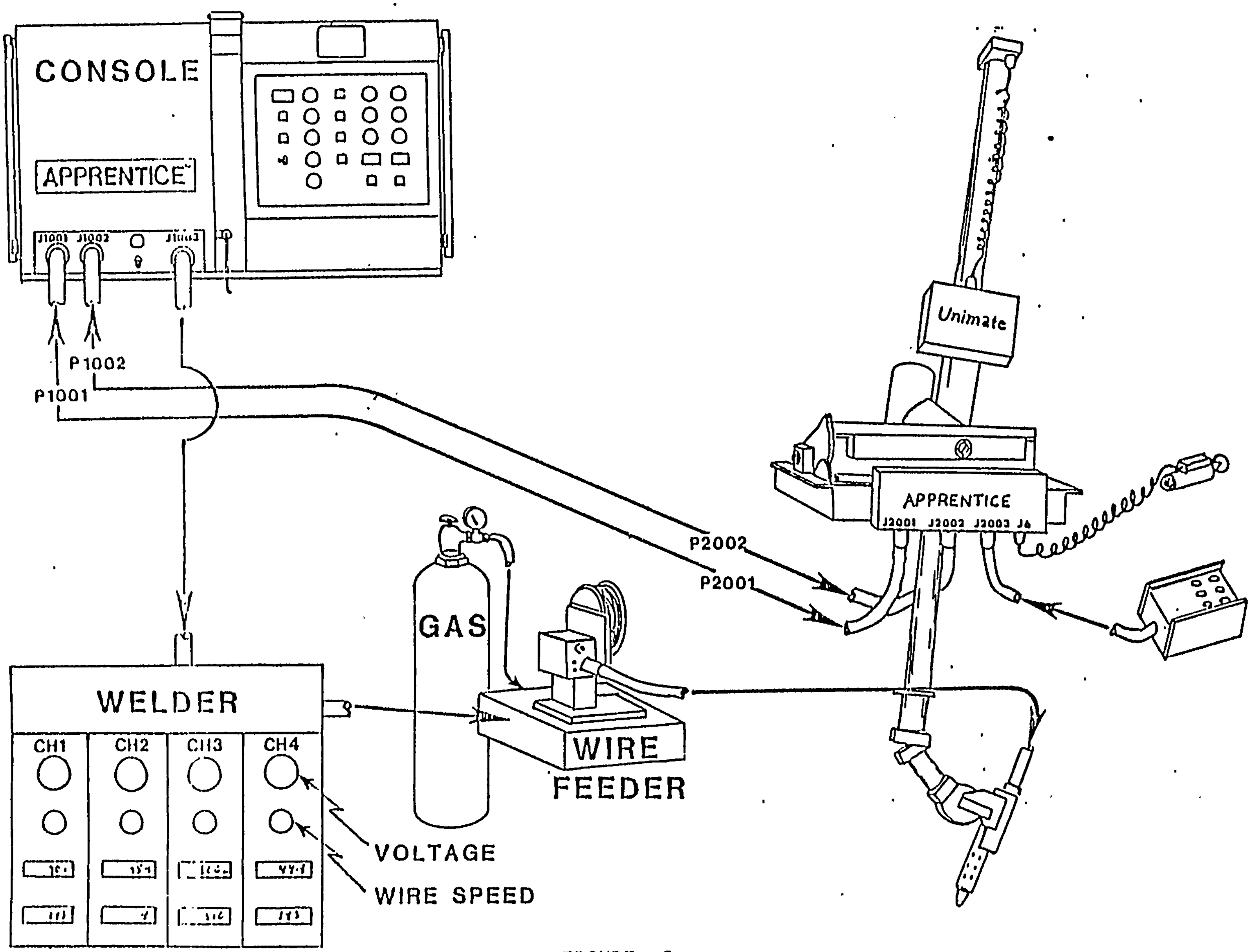
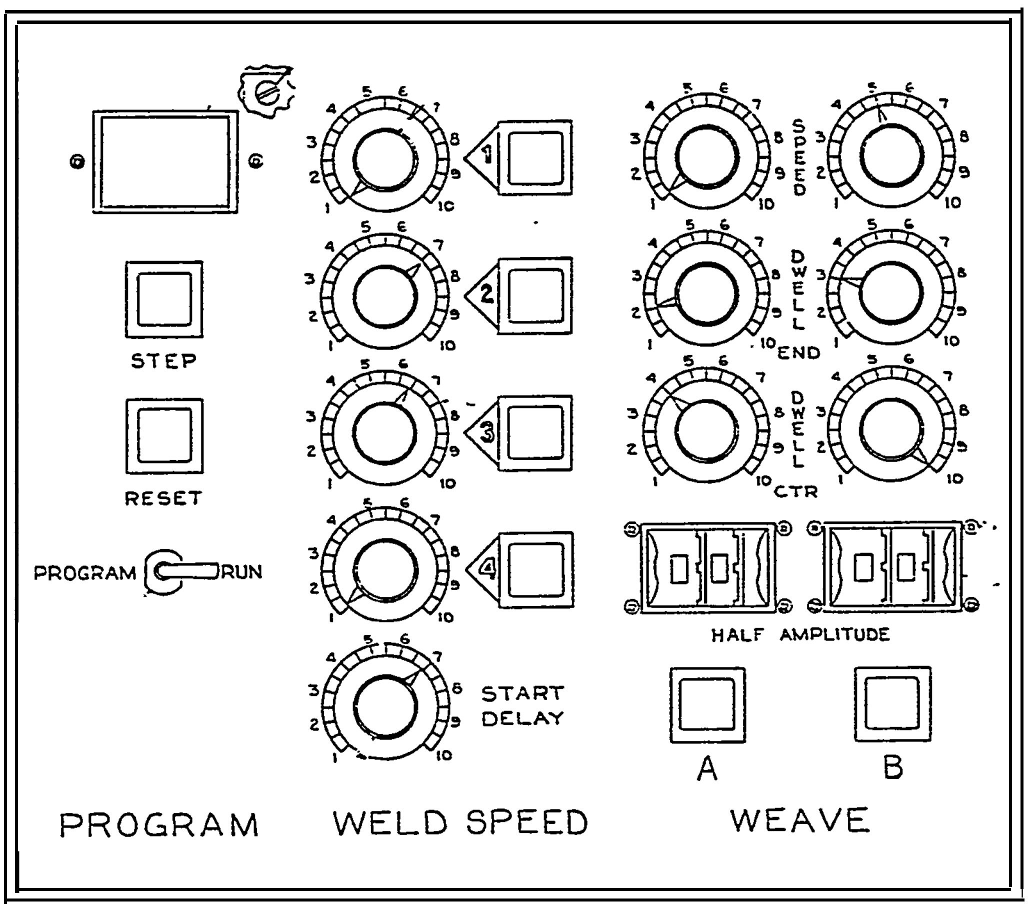


FIGURE 6



PANEL ARRANGEMENT

FIGURE 7

3.2.2.2 Travel Speed and Weave (cont'd)

capabilities were tested on flat and vertical-up fillet welds. The results of this testing revealed one major limitation. The weave sequence could only be used effectively when the weld joint was near parallel and in line with the arm/pole. This meant test pieces had to be positioned almost directly beneath the robot gimbal. The weave control adjustments were adequate when workplaces were positioned in this manner.

3.2.2.3 PC Boards

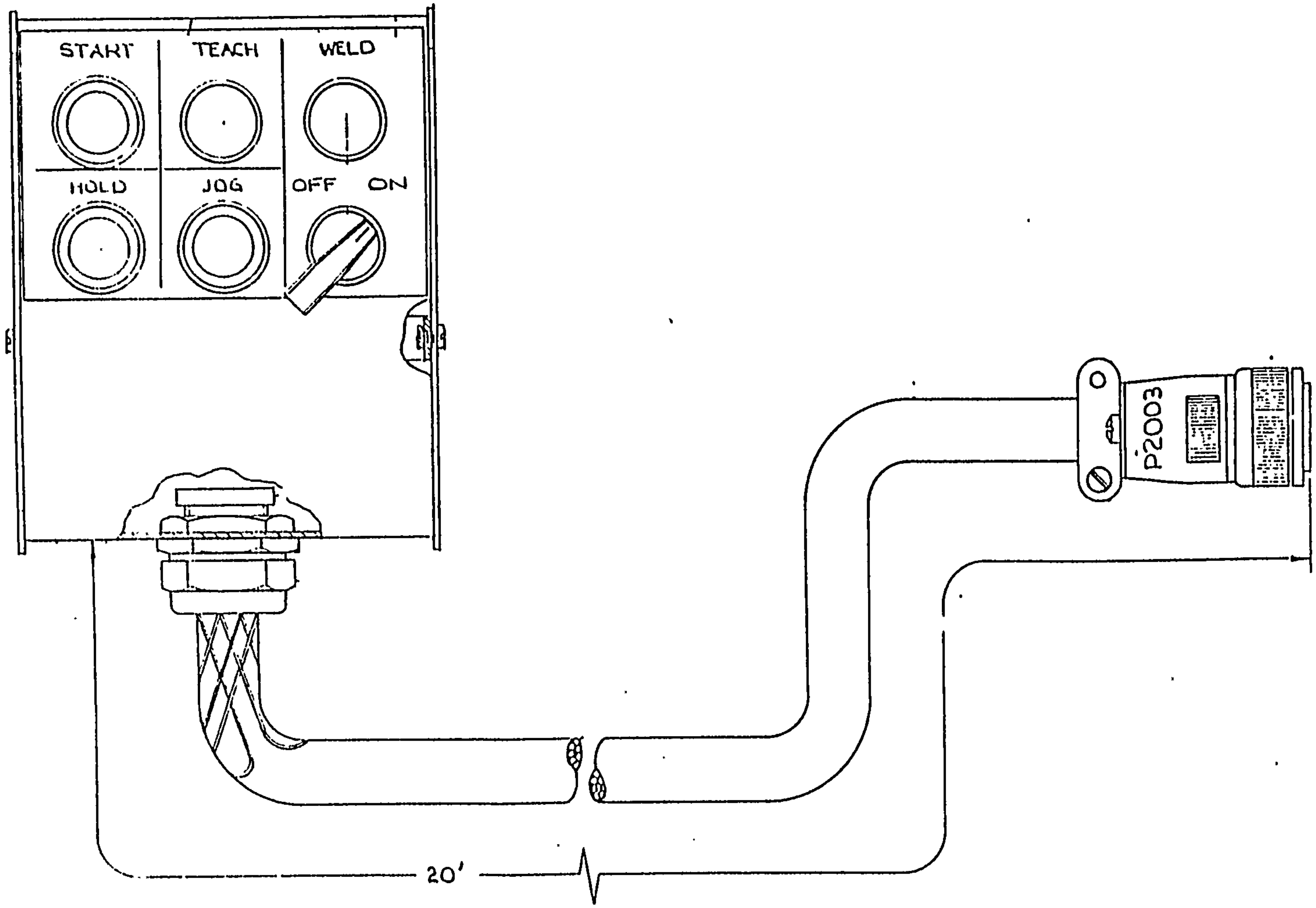
There are fourteen PC boards in the controller, some of which were replaced because of malfunctions. The memory and clock control boards were the most troublesome. Memory loss occurred frequently after several hours use on hot days (z 90°F) and was attributed to overheating of the PC boards. Inside the control cabinet the temperature would get up to 105°F. The cabinet door was opened to allow cooling, but this practice is not considered satisfactory for production use for obvious reasons such as software dust contamination, physical damage to software, etc. Forced air was later ducted to flow over the power transformer heat sink attached to the cabinet. This cooled the cabinet sufficiently without having the cabinet open.

3.2.2.4 Control Box

For simplicitv, the control box Pendent will be considered part of the controller. The control box contained several switches, see Figure 8, which were used to initiate and control the program. The Weld switch allowed a program to be run while welding or not welding. The Hold switch would hold the torch movement and weld at any point in the program. The Jog switch would increase the travel speed of the entire program to transfer speed. The control box was replaced once because of a possible switch malfunction and an update by Unimation. The design of the control box was adequate for its intended purpose.

3.2.3 Teach Control

The teach control that was furnished came with a 1 inch diameter teach wheel. This control unit was slipped over the welding torch and guided through the desired weld path using the teach wheel for spatial indexing and accurate movement over the



CONTROL BOX PENDENT

FIGURE 8

material while maintaining intimate contact, see Figure 9.

3.2.3.1 1 Inch Teach Wheel

The 1 inch diameter teach wheel "performed well on straight and gentle curved ($\geq$ 10 inch dia.) weld joints. However, fillet welds into and out of corners at various angles (45° - 135°) were tested for which the 1 inch diameter wheel proved inadequate. As a result of this, a 3/2 inch diameter wheel teach control was purchased and tested.

3.2.3.2 1/2 Inch Teach Wheel

This unit performed well in making fillet welds in corners. However, when the material being welded was preheated above 125°F the teach wheel would seize in its housing after a short period of contact with the material.

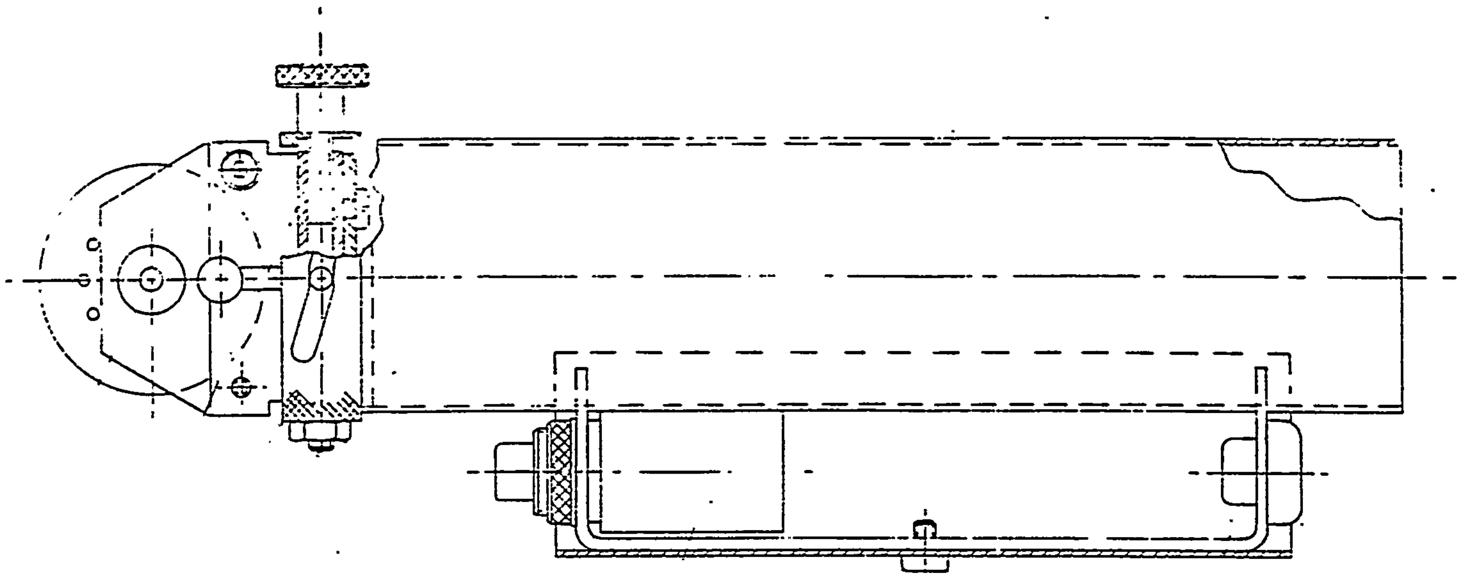
3.2.3.3 Teach Button

When teaching the robot, the weld path is recorded by depressing a teach button on the teach control. The location of this button was in an awkward position and presented difficulties in teaching joints with limited access. Unimation informed us that a redesigned teach control corrected this problem. This new teach control was not tested.

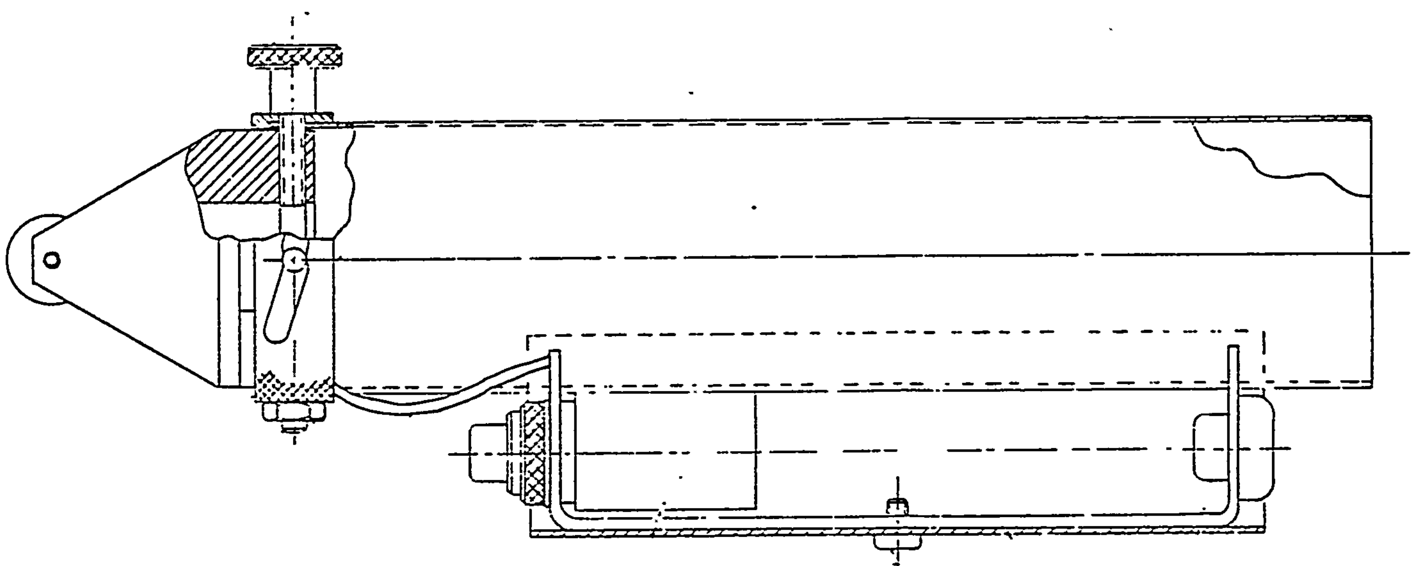
3.2.4 Wrist Assembly - The wrist assembly provides the wrist bend axis of movement. The torch mount and teach/run position ways are incorporated into the wrist. See Figure 10.

3.2.4.1 Fifth Axis Halt and Reliability

The wrist motor is geared to move at a slower rate of speed than the other four axes of movement. This slower movement is compensated for by the controller which reduces the speed of the other axes when the wrist position falls behind. This compensation is referred to as fifth axis halt. Fifth axis halt limits the robot from welding curves less than 10 inch diameter without a great amount of operator skill. Welds around pipe less than 10 inch diameter are not practical. Problems even arise when continuous fillet welds in and outof corners are attempted. Continuous welds are desirable because of the limited amount of program steps available. Skilled operators can use fifth axis halt to their advantage in situations where a delay is needed to fill a coping or corner.



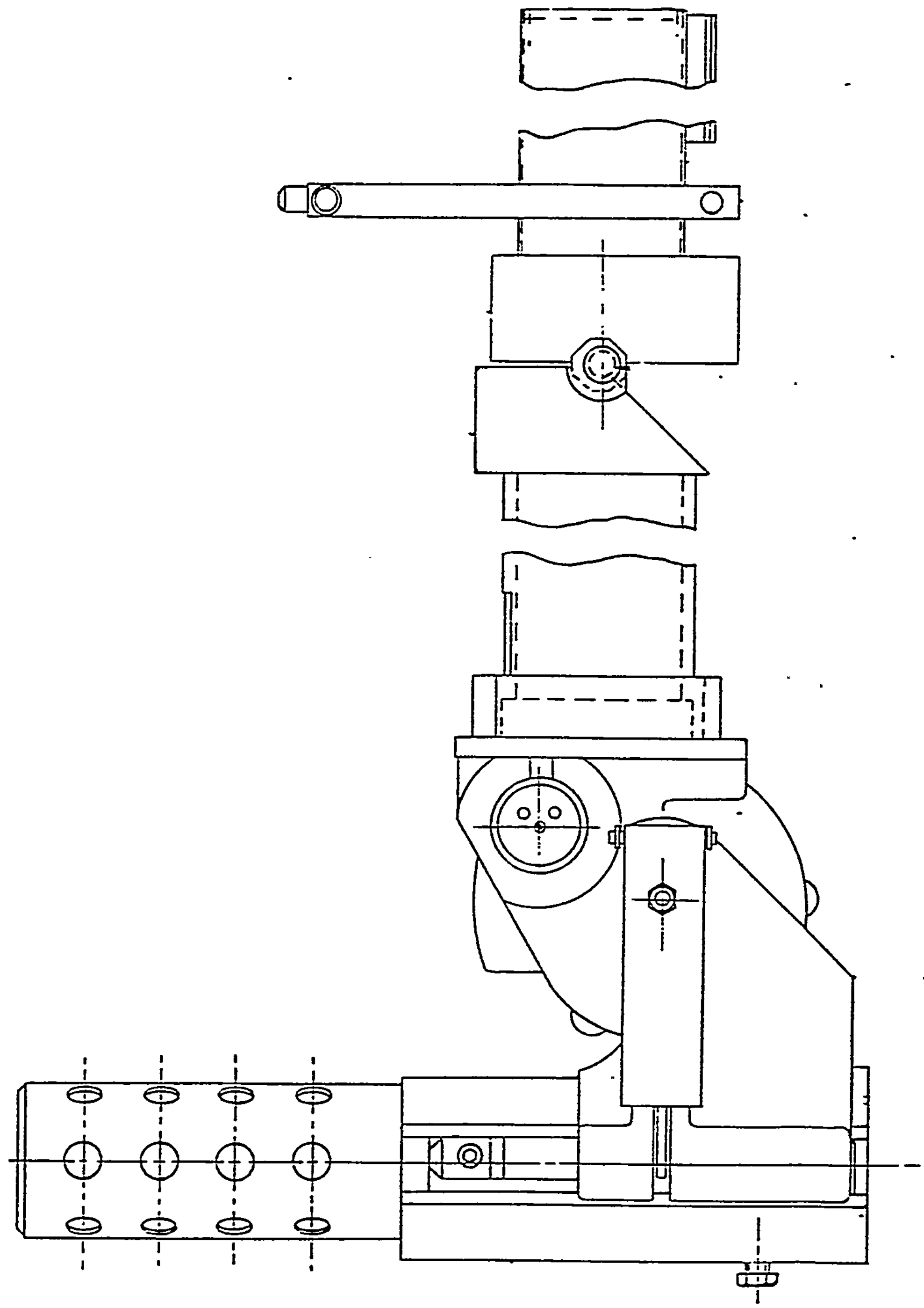
1" Teach Wheel



1/2" Teach Wheel

TEACH CONTROL

FIGURE 9



WRIST ASSEMBLY

FIGURE 10

3.2.4.1 Fifth Axis Halt and Reliability (cont'd)

During testing, the wrist assembly frequently exhibited erratic behavior, some of which was attributed to the controller. The wrist assembly was replaced once by Unimation because of malfunctions. The performance of this assembly was found lacking because of fifth axis halt limitations and high maintenance/low reliability problems.

3.3 Torches

Both the Linde MT-500 and Tweco No. 4 welding torches performed well with no malfunctions. These torches had straight barrels which provided adequate reach and accessibility to weld all the test pieces used. However, a curved torch would have been useful if a teach control unit could be designed for this. Nozzles were made of copper and required frequent cleaning and application of antispatter. See Figure 11 for illustration of the Linde MT-500.

3.4 Welding,

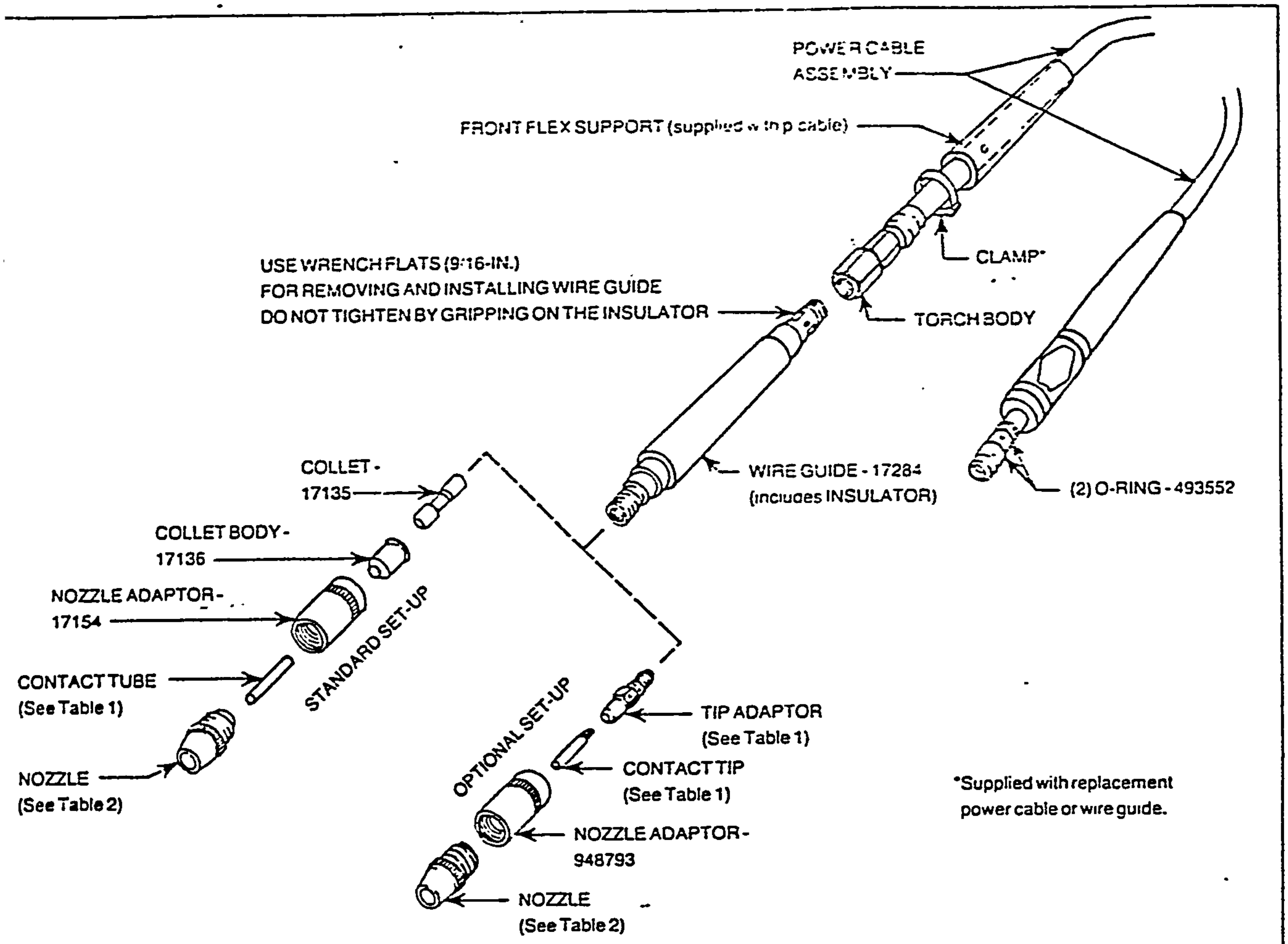
Fillet welding procedures using the flux cored arc welding process with E71T-1 classification electrode were qualified to MIL-STD-248. Prequalified procedures to AMS D1.1-82 were also written and used for testing. See Exhibit 2 for copies of these procedures. Welding was performed on mild carbon steel of the Military S-1 group, and AWS Group 1 types. No other material, electrodes or processes were attempted. Torch angles were critical and required the skill of a welder to manipulate the teach control to obtain the proper results. Fitup tolerances and torch accuracy greatly affected the quality of the weld and had to-be maintained-as indicated in Table 2.

TABLE 2

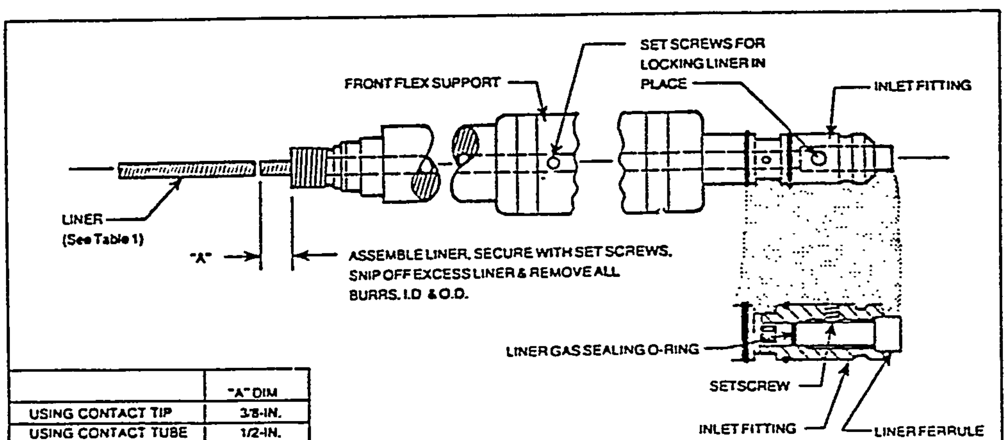
Position	Fitup Tolerance (in.)	Taught Path Deviation (in.)
Flat	+ 1/16	± 1/16
Horizontal	± 1/16	+ 1/32
Vertical-Up	± 1/32	± 1/32

3.5 Carriage

The cart mount on wheel, as mentioned, was the only carriage design See Figure 12. Performance of this carriage in the Plate Shop proved very limited even for debugging and procedure qualification testing. A platen approximately 2' x 10' x 20' in size was initially used to fixture and weld test pieces. Only a three foot

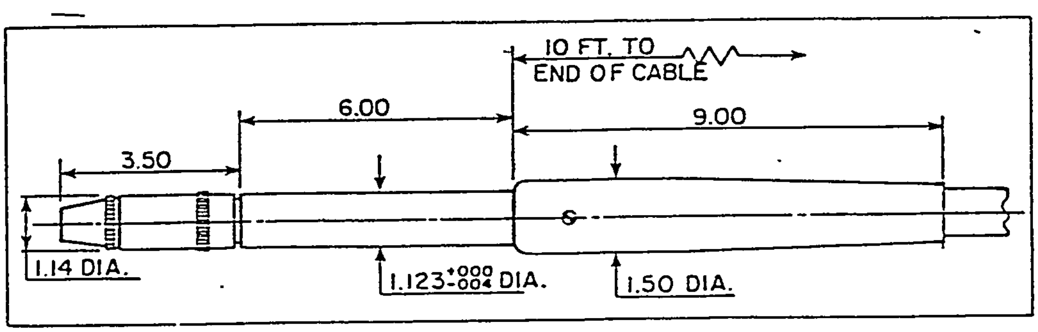


MT-500R Torch Assembly (Liner Not Shown)



	"A" DIM
USING CONTACT TIP	3/8-IN.
USING CONTACT TUBE	1/2-IN.

Installing a New Replacement Liner



Dimensional Drawing, MT-500R Torch

FIGURE 11

UNION CARBIDE CORPORATION
LINDE DIVISION
Box F-6000, Florence, SC 29501

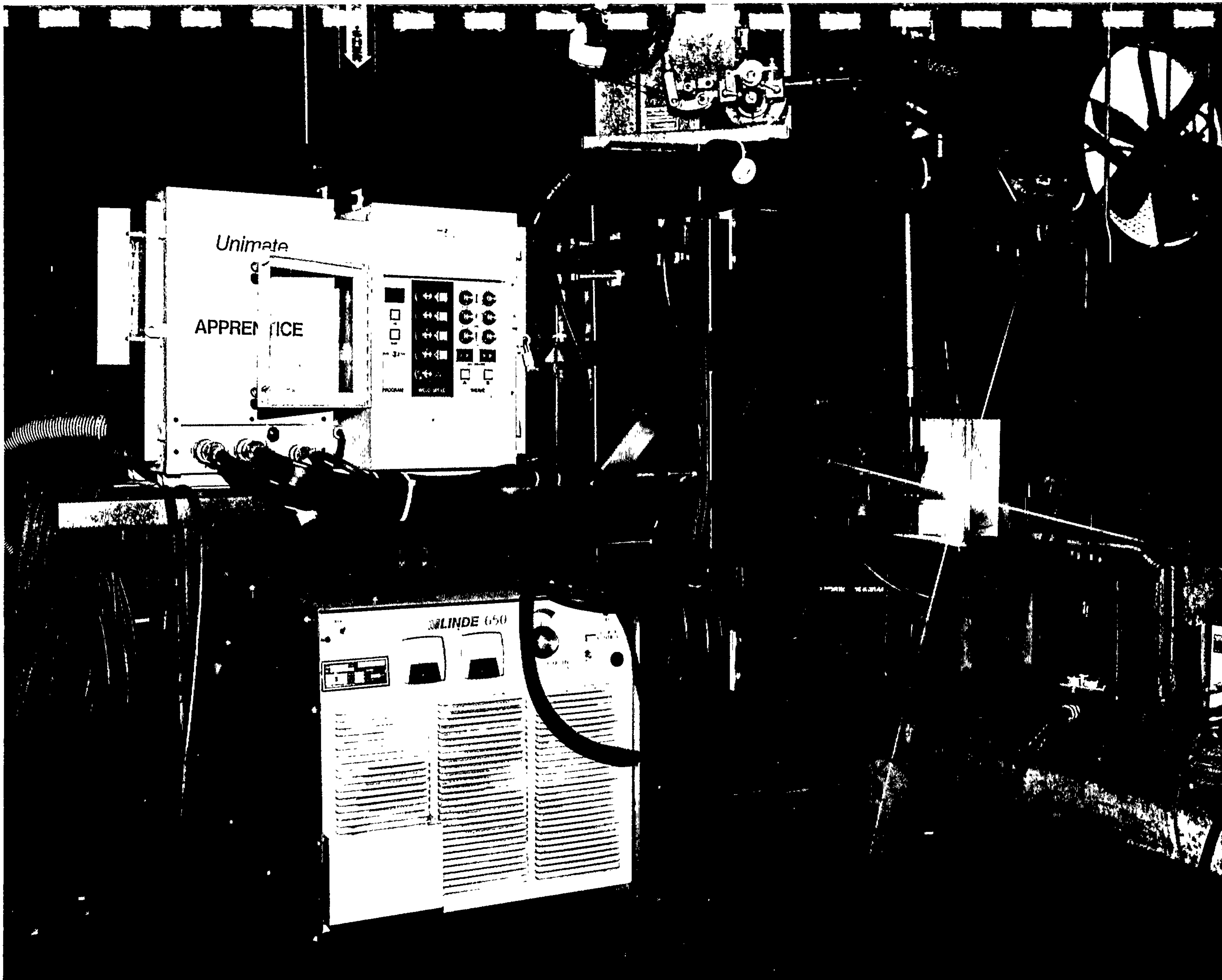


FIGURE 12 CARRIAGE & ROBOT

3.5 Carriage (cont'd)

band around the edge of the platen was accessible to the robot while positioned on the shop floor. The production workplaces welded in the Plate Shop required more flexible fixturing than this reach provided. To increase the positioning capabilities, a small positioning table was made which allowed two axes of movement on a 3' x 3' table top. See Figure 13. The cart mount on wheels carriage design, along with the small manual positioning table, performed satisfactorily for welding of test pieces. However, production workplaces in the Plate Shop would have required greater portability over a platen such as an overhead gantry carriage might have provided.

4. Improvements and Recommendations

The following comnents on improvements and/or recommendations are not complete but provide information from the tests performed up to the point of study cancellation.

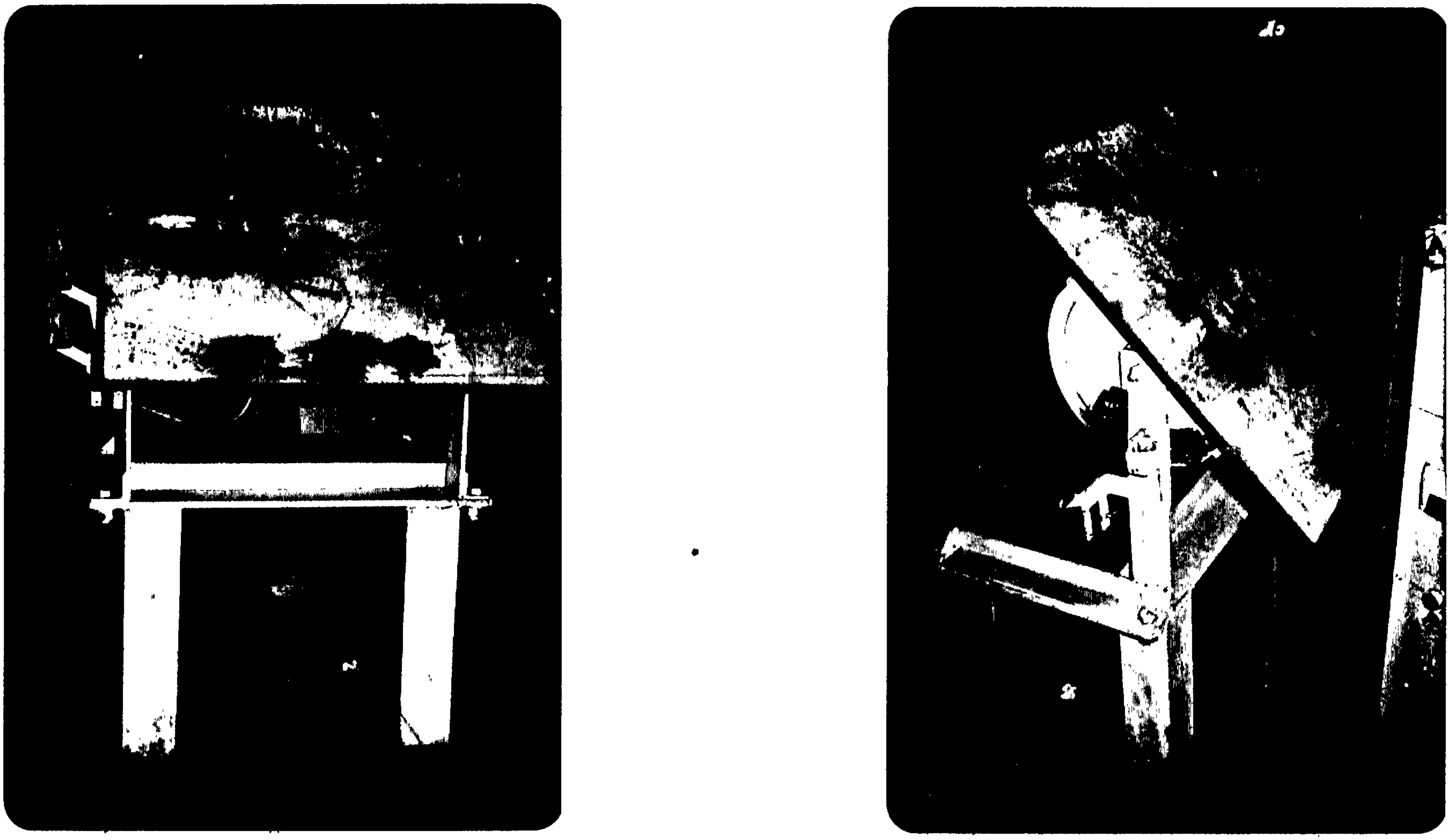
4.1 Applications

Applications for the Apprentice in shipbuilding are restricted because of the robot's limitation and fabrication practices within shipbuilding . Recommended applications for the Apprentice are as follows: 1) Work in covered areas; 2) Medium number of workplaces (100 < workplaces< 1000) should be used; 3) Workpiece size should be limited to 2' x 2' x 2' with no more than 14 welds; 4) The flux cored arc welding (FCAW) process is recommended for fillet welds on mild carbon steels; 5) Use single pass fillets only, multiple pass fillets and butt welds are not recommended; 6) Clean material is required with relatively close tolerance ($\approx \pm$ 1/16").

4.2 Apprentice Robot

The Apprentice Robot has several limitations which need to be improved on. The following is a list of recommended changes or improvements needed to make this robot operational within a shipyard.

- Improve weave capability to function in any axis.
- Increase transfer speed.
- Expand programming capabilities to more than 15 steps.
- Reduce weight of gimbal and pole assembly.
- Increase reach.
- Eliminate fifth-axis halt.
- Strengthen fragile pole assembly.
- Increase reliability of controller.
- Weatherize robot gimbal and pole assembly.
- Improve sequencing button location and teach wheel performance on teach control.



2-AXES POSITIONING TABLE
FIGURE 13

4.3 Personnel

An experienced welder was used for this study and it became evident that a skilled welder was required for welding workplaces of any complexity. It is much easier to train a welder to program this robot than it is to train a programmer/NC operator to weld.

5. Project Costs

5.1 Budget

The budget for this study was restricted to $65,000.00.

5.2 Cost At Discontinuation

Cost incurred at the point of discontinuation was approximately $22,000. The unused monies amounted to approximately $43,000.

6. Conclusion

The objectives of this study could not be met due to unforeseeable start up delays and study cancellation. However, from the work that was performed it is our opinion that the Apprentice Robot has limited portability and application in shipbuilding. To meet the objectives of this study further testing is required. However, further testing may not be practical for this robot as many advances in flexible welding automation technology have outdated the Apprentice in its current form.

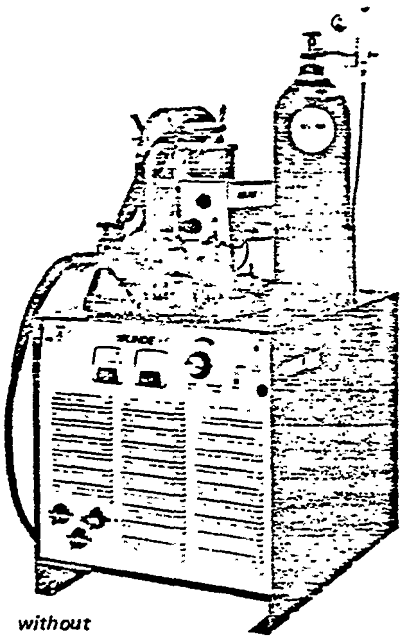
An investigation was made after this conclusion was reached. Two other users of the Apprentice Robot were contacted and the robot's performance at their facilities was discussed. Both users were not satisfied with the performance of the Apprentice and had many of the same or similar difficulties discussed in this report. This indicates that the Apprentice needs improvement and that our conclusions are valid.

EXHIBIT 1

EQUIPMENT LITERATURE

POWER SUPPLIES

LINDE 650



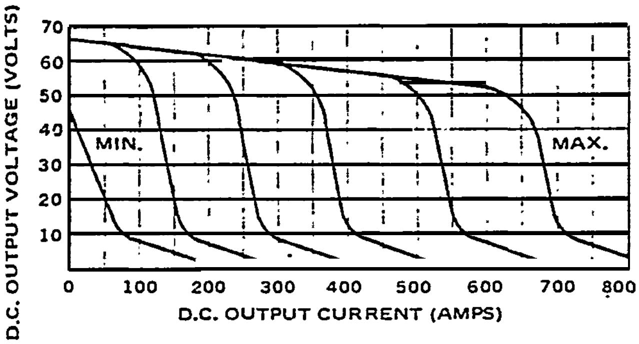
Shown without protective cover over terminals.

SPECIFICATIONS

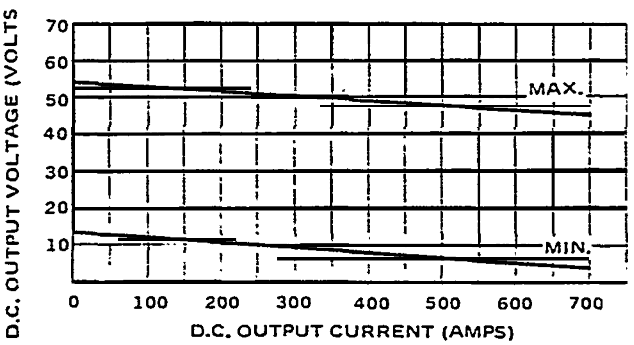
Rated Output 100% Duty Cycle		650 Amp @44 VDC
Output Voltage/ Current @ Rated Input Voltage	C.V. Mode	13 vdc Min. - 44 vdc Max. @ 650 Amps
	C.C. Mode	50 Amps @ 20 vdc thru8 650 Amps @ 44 vdc
Open-Circuit Voltage	C.V. Mode	Adjustable vdc
	C.C. Mode	65 to 66 vdc
Input Voltage		230/460 VAC, 3 Ph., 60 Hz.
Input Current @ Rated Load	230 VAC	8 Amps No Load 108 Amps. Full Load
	460 VAC	4 Amps. No Load 54 Amps. Full Load
Dimensions	Width	24-1/2-in. (622.3 mm)
	Depth	34-1/2-in. (876.3 mm)
	Height	26-in. (660.4 mm)
Net Weight Approx.		598 Ibs (271.5 kg)

FEATURES/BENEFITS

- Industrial Workhorse . . . Rated at 650 Amps, 100% duty cycle. the LINDE 650 is designed to provide high quality Mig Flux Core and Spray Arc welding performance as well as excellent results in Sub Arc applications.
- Versatile . . . With the simple flick of a switch, the LINDE 650 will provide Constant Current (CC) output for covered "STICK electrode welding, Arc Gouging or Submerged Arc welding up to 650 Amps continuous duty!
- Electronic SCR Output Control . . . One W-I-D-E range of (C.V.) Voltage/(CC) Current control make output adjustment easy.
- Line Voltage Compensated . . . Because solid state design automatically compensates for line voltage variations as great as +/- 10% , output stays constant.
- Two "Safety" Circuits . . . Both solid state breaker and overheat sensor circuits. extend the LINDE 650 service life by providing 'Shutdown" protection before electrical overloads or temperature overheating conditions can cause permanent damage - no fuse links to replace.
- Solid State Contactor . . . Provides extremely long life and eliminates the maintenance problems of mechanical contractors.
- Positive Start Circuit . . . Enables smooth, consistent starting regardless of wire type and size or shielding gas used.
- Damage Resistant Case . . . A new case design which resists damage and further protects the front panel meters and controls from day to day abuse.
- "E-Z" Access Terminals . . . Terminal studs are protectively mounted on the front panel for quick and easy connection of secondary welding and ground cables.
- Remote Voltage Control Capabilities . . . Improves productivity by allowing the welder to adjust voltage at the point of welding when the optional Remote Voltage hand control is used, or at the wire feeder when the Digimig is used.
- Integrated R. C. Network . . . Provide transient and high frequency voltage protection to improve welding performance consistency and extended power supply service life.
- Designed for Ease of Maintenance . . . All components are easily accessible and can be removed with normal hand tools.
- Bolt-in Transformer and Electric Components Allows for Easy Maintenance . . . Welded in components like Miller's must be cut out for repairs to be done!
- All Copper Transformer . . . Provides excellent thermal stability, and a longer maintenance free life. Miller DW 650, Hobart RCC-650 and Lincoln DC-600 all use aluminum transformers.
- Designed for Ease of Handling . . . Entire unit weighs only 598 lbs, net - measures 24-1/2-in. W., 26-in. H., 23- 1/2-in. D. Has lifting eye on center of gravity for safe lifting.
- Comprehensive Two Year Warranty . . . The best in the industry ! Miller, Hobart and Lincoln offer half the warranty, one year.



C.C. Mode



C.V. Mode

LINDE 650 VoltAmp Output Curves

ORDERING INFORMATION

Linde 650, 230/460 V. Input 60 Hz., PIN 677910

MIG SETS include LINDE 650 power supply, wire feeder (see table below), inlet guide, feed roll* specified, and 6 foot wire feed/power supply cable and plug assy. Digimig Mig sets include a required 6 ft./6 cond. cable assy., P/N 678399.

	MIG-31A	MIG-34	MIG-35	MIG-35 FD	DIGIMIG	DIGIMIG FD
.045	600516	600519	600522	600526*	600527	600531*
.052	600517	600520	600523		600528	
1/16	600518	600521	600524		600529	
3/32	- -	—	600525		600530	

● **For MIG-35FD (four roll drive) and Digimig FD, a feed roll kit is not included and must be ordered separately.**

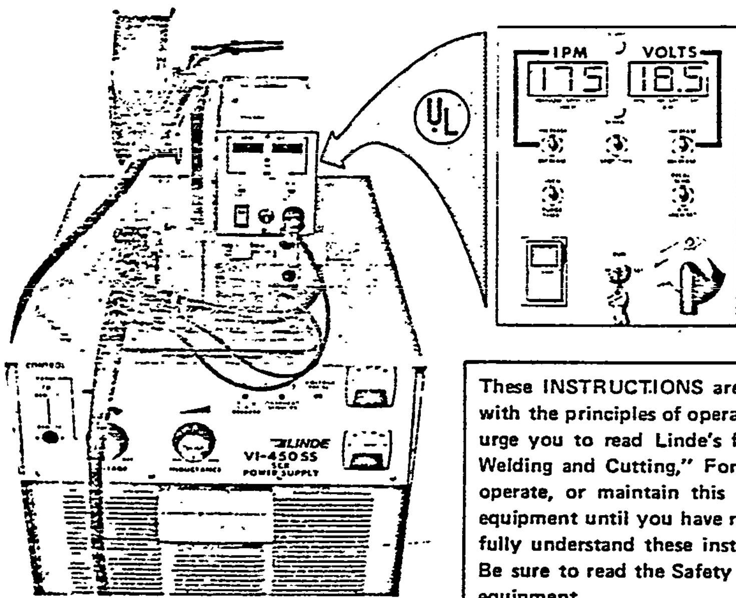
OPTIONAL ACCESSORIES

Remote Voltage Hand Control. . . . . P/N 674209
TR-7 Truck . . . .P/N 673932
Thermal Fan Kit (field installed) . . . . P/N 678302

UNION CARBIDE CORPORATION
LINDE DIVISION
Old Ridgebury Road, Danbury, CT 06817
Telephone: (203) 794-2000

INSTRUCTIONS for

L12-789
June, 1981



DIGIMIG WIRE FEEDER

P/N 677567 w/2-ROLL DRIVE
P/N 677815 w/4-ROLL DRIVE
(See Supplement L-12-821)

These INSTRUCTIONS are for experienced operators. If you are not fully familiar with the principles of operation and safe practices for electric welding equipment, we urge you to read Linde's free booklet, "Precautions and Safe Practices for Electric Welding and Cutting," Form 52-529. Do NOT permit untrained persons to install, operate, or maintain this equipment. Do NOT attempt to install or operate this equipment until you have read and fully understand these instructions. If you do not fully understand these instructions, contact your supplier for further information. Be sure to read the Safety Precautions on page 2 before installing or operating this equipment.

SPECIFICATIONS

Input Power Required	115 volts, 50/60 Hz, single phase
Wire Feed Speed Range	20-575 in./min. (.5-15.2 m/min.)
Wire Sizes Accommodated:	
Hard/Soft –	.030 thru 1/8-in. (.8 thru 3.2 mm)
Flux Cored –	.045 thru 1/8-in. (1.2 thru 3.2 mm)
Length	18.5-in. (470 mm)
Width	13-in. (330 mm)
Height	16.5-in. (419 mm)
Weight (less wire)	46-lbs. (21 kg)

NOTE: For changes made to Control, see Section IV-A.

I. INTRODUCTION

The ultimate in semiautomatic mig welding and control is Linde's DIGIMIG. This microprocessor designed digital control is the most technologically advanced and functionally complete wire feeder offered in the welding marketplace.

A. FEATURES/BENEFITS

- Exclusive Microprocessor Design - - Permits virtually every desirable welding function needed for manual mig welding to be programmed without increasing the control size. Never have to add "piggy-back" or "building block" modules to provide additional features.
- Presettable Welding Voltage and Wire Feed Speed - - Provides ability to easily and accurately preset exact welding parameters desired before striking an arc. When arc is established, both voltage and wire feed speed are automatically maintained.
- Individual Digital LED Meters Provide Large 1/2-in. Readout of Voltage and Wire Feed Speed - - Continuous display of preset and then actual welding voltage and wire feed speed for accurate observation.
- Dual Schedule Capability - - Enables operator to have two different sets of weld parameters at his fingertips. Digimig's microprocessor allows operator to change schedules with a simple squeeze of a standard torch trigger switch.
- "Lock-In" Key - - Allows preset welding parameters to be "locked-in" for positive supervisory control of weld quality. With key turned to "set" position, all parameters may be reset to new values at any time.
- Automatic "Shut Down" - - Assures welding is done at the preset parameters. Unit automatically shuts down if, for any reason, either the VOLTS or IPM cannot be maintained for a preprogrammed time period. Simultaneously, cause is indicated by flashing digital display.
- Arc Hours Readout - - This unique feature provides direct measure of "Productivity" by accumulating and displaying, upon command, actual welding Arc Hours (A.H.).
- Toggle Switch Adjustment of Weld Parameters by Fine Increments or Rapid Coarse Adjustment - - Allows quick, easy, and accurate adjustments of welding parameters.
- Patented Adaptive Anti-Stick Circuit - - Automatically adjusts the same amount of wire burnback, regardless of wire size, speed or voltage.

(continued)

LINDE
UNION CARBIDE

EXHIBIT 2

WELDING PROCEDURE SPECIFICATIONS

TODD PACIFIC SHIPYARDS CORPORATION LOS ANGELES DIVISION	PRODUCTION WELDING PROCEDURE (Approval Pending)	No: 55-2 Rev: 0 Issued 4/15/83 Page 1 of 1

DESCRIPTION: AUTOMATIC FLUX CORED ARC WELDING PROCEDURE FOR WELDING LOW AND MEDIUM CARBON STEELS (S-1 to S-1).

WELDER QUALIF.	MIL-STD-248C Automatic Plate Assembly Test	*PROCEDURE QUALIF. STD.*	MIL-STD 248 Par. 4 MIL-STD-278 NAVSHIPS 0900-000-1000 (1)
BASE METALS	S-1 to S-1	*PROCESS*	Flux Cored Arc Welding (FCAW) Automatic
SPEC./TYPE FILLER METAL	MIL-E-24403(SH) E71T-1 AWS A5.20 E71T-1	*POWER SOURCE POLARITY*	D.C.R.P., Electrode positive
POSITION OF WELD	Flat Fillet Horizontal Fillet	*FLUX/INERT GAS WITH FLOW RATE*	CO_2 per BB-C-101A, Gr. B,Ty.1 45 cfh min.
JOINT PREPARATION & SIDE NUMBER	Welded surface is to be free from loose or thick scale, slag, rust, moisture, grease and other foreign material including primer. Single or multiple pass fillets may be used within the limits specified herein.		
INTERPASS CLEANING	Remove slag and foreign material from joint.		
REPAIRS	Remove all defects before welding next bead. Chip, grind or arc gouge.		
PREHEAT TEMPERATURE	70°F minimum		
POSTHEAT TEMPERATURE	None	*INTERPASS TEMPERATURE*	70°F minimum
HEAT TREATMENT	None	*ELECTRODE CONTROL*	TPLA Weld Proc. Man. N-1, Sec. 3
WELD TECHNIQUE	Do not weld in drafts greater than 5 mph.		

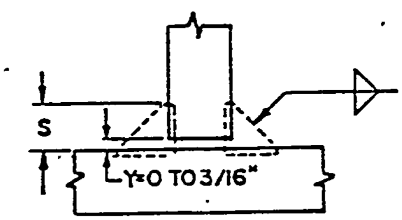
PASS NUMBER	*FILLER METAL SIZE*	*AMPERAGE RANGE*	*ARC VOLTAGE RANGE*	*POSITION*
1-finish	.052	100-300	21-28	F, H
1-finish	1/16	150-400	21-32	F, H

NOTES:
1) Peening not permitted.
2) Inspection to be in accordance with the applicable Military and/or Naval Specification.

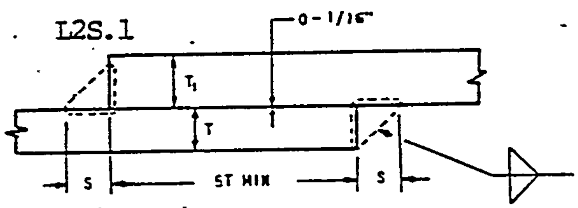
JOINT DESIGN: See Below *SPEC.:* MIL-STD-22 *THICK. RANGE QUAL.:* 0.058"-0.4125"

SKETCH OF WELD LOCATION & TYPICAL PASS SEQUENCE

PT2S.1
PT2S.2
PT2S.3



L2S.1



NOTES: 1. Where Y is greater than 1/16 inch as a nominal condition, S shall be increased by an amount equal to the excess of the opening above 1/16 inch.
2. Fillet size(s) shall be governed by design requirements.

APPROVAL: TPSIA Weld. Engr. Dept. John P. Mariel

Customer

TODD PACIFIC SHIPYARDS CORPORATION LOS ANGELES DIVISION	PRODUCTION WELDING PROCEDURE	No: 55-3 Rev: 0 Issued 10-12-82 Page 1 of 3

DESCRIPTION: AWS D1.1 FILLET WELDING ON LOW & MEDIUM CARBON STEELS, AUTOMATIC

WELDER QUALIF.	AWS D1.1, Section 5, Part D	*PROCEDURE QUALIF. STD.*	AWS D1.1 - Prequalified
BASE METALS	Groups I & II, ASTM A36 (Typ.)	*PROCESS*	Flux Cored Arc Welding, Automatic (FCAW)
SPEC./TYPE FILLER METAL	AWS A5.20 E71T-1	*POWER SOURCE POLARITY*	DC Electrode Positive Reverse Polarity
POSITION OF WELD	Flat, Horizontal, Vertical	*FLUX/INERT GAS WITH FLOW RATE*	CO_2, 45 cfh
JOINT PREPARATION & SIDE NUMBER	Welded surface is to be free from loose or thick scale, slag, rust, moisture, grease and other foreign material including primer. Single or multiple pass fillets may be used within the limits specified herein.		
INTERPASS CLEANING	Remove slag and foreign material from joint.		
REPAIRS	Remove all defects before welding of next bead. Chip, grind or arc gouge.		
PREHEAT TEMPERATURE	70°F minimum		
POSTHEAT TEMPERATURE	None	*INTERPASS TEMPERATURE*	70°F minimum
HEAT TREATMENT	None	*ELECTRODE CONTROL*	TPLA Weld. Proc. Man. N-2, Sec. 6-2
WELD TECHNIQUE	0-15° Push Angle. Do not weld in drafts greater than 5 mph.		

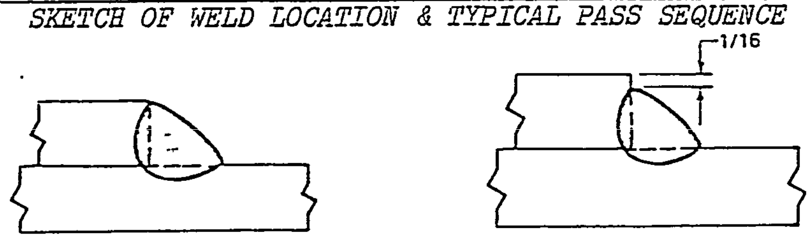
PASS NUMBER	*FILLER METAL SIZE*	*AMPERAGE RANGE*	*ARC VOLTAGE RANGE*	*POSITION*
	.052	175-200	23-25	V-up
Repair only	.052	175-200	23-25	V-down
	.052	275-350	22-29	F, H
	1/16	175-250	22-25	V-up
Repair only	1/16	175-250	22-25	V-down
	1/16	150-400	22-32	F, H

NOTES:

1) Maintain a 3/4"-1" contact tube to work distance.

JOINT DESIGN: Fillet *SPEC.:* AWS D1.1-82 *THICK. RANGE QUAL.:* Unlimited

SKETCH OF WELD LOCATION & TYPICAL PASS SEQUENCE



Base metal less than 1/4 thick

(A)

Base metal 1/4 or more in thickness

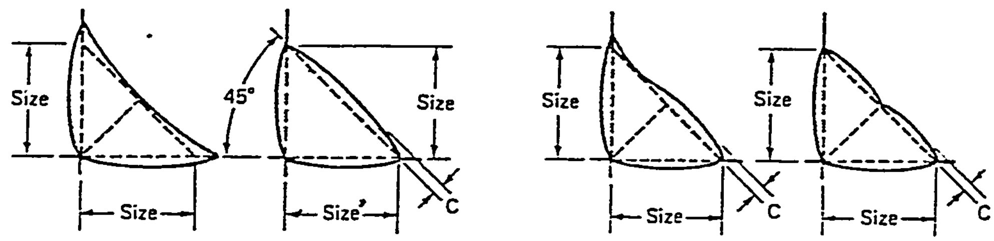
(B)

Maximum size of fillet weld along edges

APPROVAL: TPSLA Weld. Engr. Dept. John P. Maciel

Customer

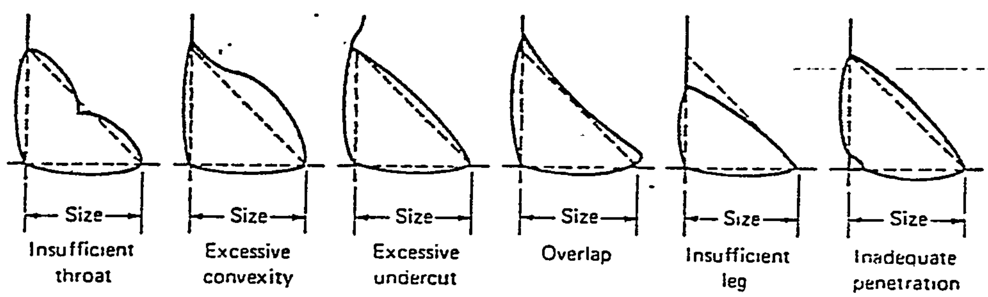
DESCRIPTION: AWS D1.1 FILLET WELDING ON LOW & MEDIUM CARBON STEELS, AUTOMATIC



Note: Convexity, C, of a weld or individual surface bead shall not exceed 0.07 times the actual face width of the weld or individual bead, respectively, plus 0.06 in. (1.5 mm).

Desirable fillet weld profiles

Acceptable fillet weld profiles



Unacceptable fillet weld profiles

ACCEPTABLE AND UNACCEPTABLE WELD PROFILES

APPROVAL: TPSLA Weld. Engr. Dept.
Customer

DESCRIPTION: AWS D1.1 FILLET WELDING ON LOW & MEDIUM CARBON STEELS, AUTOMATIC

Minimum Fillet Weld Size For Prequalified Joints

Base metal thickness of thicker part jointed (T) in.	Minimum size of fillet weld* in.	
$T \leq 1/4$	1/8**	Single pass welds must be used
$1/4 < T \leq 1/2$	3/16	
$1/2 < T \leq 3/4$	1/4	
$3/4 < T$	5/16	

*Except that the weld size need not exceed the thickness of the thinner part joined. For this exception, particular care should be taken to provide sufficient preheat to ensure weld soundness.

**Minimum size for bridge applications is 3/16 in.

Maximum Electrode Diameter and Fillet Weld Size

Max. Electrode Diameter in.	Welding Position*	Max. Size Of Fillet Weld** in.	Welding Position*
5/32	F, H	1/2	F, V
3/32	V	3/8	H
5/64	OH	5/16	OH

*Flat (F), Vertical (V), Horizontal (H), Overhead (OH).
**Maximum size of any one pass.

APPROVAL: TPSLA Weld. Engr. Dept.____________________
Customer

SHIP PRODUCTI
FACILITIES IMF
OUTFITTING AND PI
INDUSTRIAL ENGINEERING FC
SHIPBUILDING STA
DESIGN/PRODUCTIO
COMPUTER AIDS FO
SURFACE PREPARATION
ENVIRONMENT
TECHNOLO
WEL
RE